STUDY ON STABILITY OF PILLARS IN COAL MINES THROUGH EMPIRICAL MODELS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY
IN
MINING ENGINEERING

BY

BALGOPAL SAHU

110MN0401

Under the Guidance of

Prof. S. Jayanthu

Department of Mining Engineering
National Institute of Technology
Rourkela

2015

National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that the theory entitled, **"Study on stability of pillars in coal mines through empirical models"** put together by **Mr. Balgopal Sahu**, **110MN0401** in partial fulfillment of the necessity for the grant of Bachelor of Technology Degree in Mining Engineering at the National Institute of Technology, Rourkela is a real work completed by him under my supervision and direct.

To the best of my insight, the matter exemplified in the proposal has not been submitted to any College/Institute for the recompense of any Degree or Diploma.

Date –

Prof. S. Jayanthu

Department Of Mining Engineering

National Institute of Technology

Rourkela – 769008

ACKNOWLEDGEMENT

Most importantly, I express my significant appreciation and obligation to **Prof. S. Jayanthu**, Professor of Department of Mining Engineering for permitting me to bear on the present topic ‘’**Study on stability of pillars in coal mines through empirical models’’** and later on for his rousing direction, useful feedback and important recommendations all through this venture work. I am all that much appreciative to him for his capable direction and torment requiring exertion in enhancing my comprehension of this vent.

At the last, my true on account of every one of my friends who have quietly amplified a wide range of makes a difference for finishing this task.

Balgopal Sahu

110MN0401

Department Of Mining Engineering

National Institute of Technology

Rourkela – 769008

CONTENTS

ABSTRACT

Mining is the extraction of profitable minerals or other land materials from the earth, generally from a mineral body, vein or (coal) crease. Mining includes distinctive techniques like prospecting for metal bodies, dissecting the possibility of extraction, gainfulness of the operation, extraction of the sought materials. One of such systems is the Bord and Pillar system for mining which is one of the most established strategies for mining. The accomplishment of Bord and Pillar mining is selecting the ideal pillar size. In the event that the pillars are too expensive, then the extraction proportion abatements prompting less productivity and if the pillars are too little it jeopardizes the general mine wellbeing. Indian mines have around 60 % of the coal hindered as pillars. Geotechnical variables of an adjacent underground coal mine has been dead set in the research center. Distinctive methodologies of pillar configuration have been thought about. Variety of security element with width to stature proportion of pillar, extraction rate and profundity of spread has been dead set and conclusion has been made. The wellbeing and attainability of mining system is acquired through an ideal connection between security variable and extraction rate.

This thesis contains the study of RK6 mine and GDK8 incline, the data collected from these mines and the results are found out to be 3.49MPa, 6.3MPa in RK6 and GDK8 respectively shows the maximum stress from Tributary area approach. Similarly 7.62MPa and 7.29MPa respectively for mine RK6 and GDK8 incline shows the maximum stress from Wilson's approach. Wilson's approach on stress over pillar shows maximum stress of. Strength of the pillars through six approaches indicated minimum strength of 11.17 MPa and 11.25 MPa in RK6 and GDK8 respectively. Safety factors are 2.11 and 2.3 for RK-6, and GDK 8 with variation of about 10% compared to the Tributary Area Approach. On the whole, pillars are stable with more than 1.5 safety factor for both of the mines conforming to the field observations.

List of figures

List of tables

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

Mining is one of the oldest industries in the world. The two general types of mining practices include opencast mining and underground mining. The two common methods of underground mining include Longwall mining and Bord and Pillar method of mining. The method mostly prevalent in the Indian underground mines is the Bord and Pillar method of mining because of its history and ease of operation.

The most important aspect of Bord and Pillar mining is the design of pillars. The design of pillars not only affects the support of the overburden but also determines the percentage of extraction and design of the ventilation network. The shape and size effect of the pillar also plays an important role. Generally square pillars are preferred for a certain fixed gallery width and height of working. Various geotechnical factors like depth of mining, inclination of seam, insitu properties of coal, height of working and gallery width are taken into consideration while designing of a pillar. The load on the pillar is generally calculated based on the tributary area method and pillar strength is determined through various empirical equations. The ratio of strength of pillar to the stress on the pillar gives the safety factor. An optimum correlation between safety factor and extraction percentage determines the feasibility of working.

1.1 Objectives of the Project

The objective of the project is to study the stability of pillars through empirical modeling for the geo-mining conditions of RK.6 and GDK.8 Incline, SCCL.

CHAPTER 2

LITERATURE REVIEW

2.0 LITERATURE REVIEW

The pillar load might be estimated from tributary area theory, also the pillar strength from empirical formulas and laboratory coal strength testing. In recent times, powerful design approaches have developed after analysis of large data bases of real world pillar successes and failures. These contain the Analysis of Retreat Mining Stability (ARMPS), the Analysis of Longwall Pillar Stability (ALPS), the Mark-Bieniawski rectangular pillar strength formula, and guidelines for avoiding massive pillar collapses. A different model divides pillar failure into three categories:

- **Slender pillars (w/h<3.0),** which are subject to quick collapse
- **Squat pillars (w/h>10),**which are dominated by entry failure (rib, roof, or floor) and coal bumps
- **Intermediate,** in which pillar squeezes appear to be the best common failure mode

Several pillar design formulas were suggested in the early period, based upon laboratory testing, full-scale pillar testing, and back-analysis of mine case histories (Mark and Barton, 1996). They were technologically advanced for an industry that depend on almost completely on room and pillar mining at comparatively shallow depth.

The energy disaster of the 1970’s and 1980’s faced renewal of attention in coal pillar design. A number of aspiring field studies were carry out, numerous of them sponsored or lead by the U.S. Bureau of Mines. By 1980, The “classic” pillar design methodology had completely developed. It comprised of three stages:

- Estimating the pillar load by tributary area theory;
- Estimating the pillar strength with a pillar strength formula;
- Computing the pillar safety factor (SF).

Various formulas were accessible for the estimation of pillar strength as a function of two variables, the pillar's width to height ratio (w/h) and the coal seam strength calculated from laboratory testing (Bieniawski, 1984)

Arthur Wilson of the British National Coal Board was the first to yield a completely different approach to pillar design. His analytic method preserved the pillar as a complex structure, with a non-identical stress gradient, a build- up of confinement about a high stress core, and progressive pillar failure. Even if his mathematics were seriously weak (Mark, 1987; Salamon, 1992), Wilson's basic concepts are now mostly accepted and inspire nearly all modern numerical models.

Since 1990, the number of pillar strength formulas and numerical models had increased, but their forecast for squat pillars varied broadly. One study associated 10 formulas, and establishes that some expected that pillar strength would increase exponentially as the w/h ratio increased, it would incline towards a maximum limiting value, and still others expected a midway, linear increase.

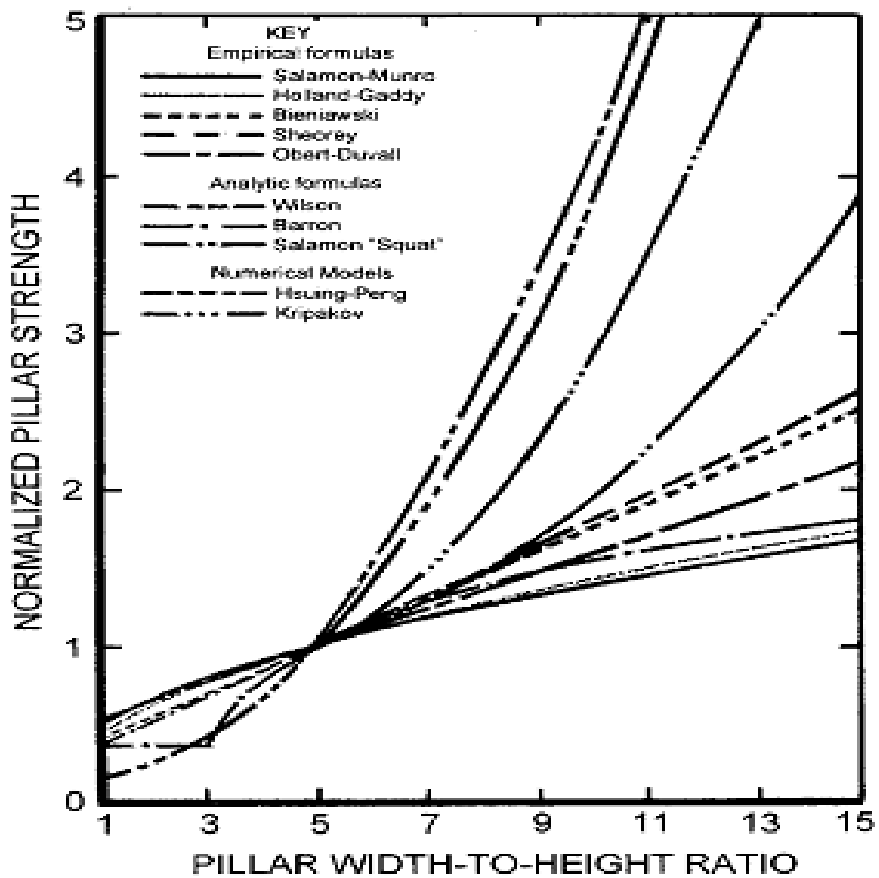

Figure 1. Comparison of pillar strength predictions from various formulas.

Many empirical approaches were suggested by various investigators. Details of some of the approaches are given below.

2.1 Coal Pillars-Design Approaches

2.1.1 Ultimate Strength

The design determines the strength of a pillar on the basis of its geometry, size and the compressive strength of the material.

- This methodology will hope to measure up the normal heap of the column to its extreme quality to focus its wellbeing component esteem.

- The fundamental suspicion of this methodology is that, once a definitive quality is conquer the column will have zero quality, which is most certainly not entirely valid actually.

2.1.2 Progressive Failure

The configuration accepts a non-uniform anxiety dispersion inside the column.

- The disappointment of a pillar starts at the purpose of extreme quality, and slowly advances to extreme disappointment.
- Numerical Models can embrace both extreme quality and dynamic disappointment approaches.

Customarily, all column outline recipes utilize a definitive quality hypothesis. Each of these "excellent" column outline recipes comprised of three stages:

- Estimating the pillar load
- Estimating the pillar strength
- Calculating the pillar safety factor.

Exemplary exact column quality equations normally take after one of two general structures.

$$\sigma_P = \sigma_{S'}\left(a + b\frac{W}{H}\right)$$

or

$$\sigma_P = K\frac{W^{\alpha}}{H^{\beta}}$$

Where σ_p= pillar strength; σ_p = strength of in-situ coal or rock; W = pillar width; H= mining height, α and β are regression constant and K = a constant depending on the field.

Pillar strength formulas by Obert and Duvall (1967) and Bieniawski (1968), Sheorey follow the first form, whereas formulas by Salamon and Munro (1967) and Holland (1964) follow the second.

2.2Load on the Pillars

The load on the pillar may be evaluated utilizing any of the accompanying two methodologies:

2.2.1 Tributary Area approach

This relation is used to measure the distribution of load on the uniform sized excavations/pillars/stooks. The normal stress perpendicular to the seam,

$$\boxed{\sigma_n = \gamma H \left(\cos^2\alpha + k \sin^2\alpha \right)}$$

And the average stress on the pillar, P or σ_p:

$$P = \sigma_p = \sigma_n / (1 - R) = \sigma_n \left[(B + w) / w \right]^2$$

Where,

H = depth of cover, m

B = width of the mined out area, m

У= unit rock pressure = 0.025 MPa/m of depth

R = extraction ratio

w = width of the pillar, m

α= dip of the seam

The value of k, which is the ratio of horizontal to vertical in-situ stress, is taken as 1 in the absence of actual stress measurements.

$$\sigma_n = \gamma H$$

2.2.2 Wilson's Approach

The pressure (P in MPa) advancing over the chain of columns with goaf on one or both sides is evaluated utilizing the accompanying connection:

$$P = \rho\ (W_2+B)\ \{ H^*(w_1+L) - (L^2/1.2) \} / (W_1^*W_2),\ \text{for } L/H < 0.6$$

Where,

ρ= unit rock pressure =0.025 MPa/m,

H = depth of cover, m

W_1 = width of the pillar, m

W_2 = length of the pillar, m

B = gallery width, m

L = extraction width, m

σ_c = compressive strength of 2.5 cm cube coal, taken as 30 MPa

h = extraction height, m

2.2.2 Pillar Stress

$$\sigma_p = \frac{\gamma H}{1-R}$$

Where H = depth of cover, γ = unit weight of overburden, Can be expressed in terms of extraction ratio R = total void/ total area.

2.2.3 Safety factor during development

$$SF=\frac{Strength\ of\ pillar}{Stress\ on\ pillar}= \frac{S_p}{\sigma_p}$$

2.3 PILLAR LOADING

Tributary area loading idea it has particular after limits:

- The consideration of tributary burden is being confined to the ordinary pre-mining anxiety to apply to the vertical rule pivot of the column emotionally supportive network. It expects that all different anxiety segments of the mining anxiety field have no impact on the pillar execution.

- Tributary assessments are substantial just if the geometry of pillars is exceedingly general what's more, it is rehash itself over a relative separation. Along these lines, any inconsistency (i.e. strong ribs) will be moderately far from most of the pillars, so it's generally impact on the whole column structure can be ignored.

- Tributary is pertinent for bolster columns under static burden. For illustration, it can't evaluate the projection stack on a button column.

- Tributary burden is excessively progressive for longwall mining. It overestimates the column loads, in light of the fact that tributary burden expect the heap is consistently circulated over the columns, which is not the situation.

2.4 Pillar Strength Equations

2.4.1 Overt-Duvall/Wang Formula

It was derived after laboratory tests on hard rock and elasticity considerations the similar relationship as did Bunting in 1911. Greenwald et al. (1939) remark that this method of an expression for pillar strength was suggested in 1900 for anthracite after laboratory tests made for the Scranton Engineers Club. The formula is given as

$$\sigma_p = \sigma_1 \quad 0.778 + 0.222\frac{w}{h}$$

Limitations: Developed for hard rock specimen but can also be applied to coal seams and found to be suitable for Wp/h ratio upto 8.

2.4.2 Holland-Gaddy Formula

$$\sigma_p = k\,\frac{\sqrt{w}}{h}$$

Holland (1964) extended Gaddy's work (1956) and proposed this formula. K is Gaddy's constant and the units of w_p and h should be expressed in inches. This formula works well for a coal pillar safety factor of 1.8~2.2 with a wp/h ratio between 2 to 8.

2.4.3 Holland Formula (1973)

$$\sigma_p = \sigma_1\sqrt{\frac{w}{h}}$$

Given distinctive recipe and prescribed security safety factor for utilizing this equation is 2.0.Where σ1 is the strength of cubical pillars (w = h = 1). In effect, it can be understood as the strength at the critical size of coal specimens and is to be estimated. The recommended factor of safety is 2.0.

2.4.4 Bieniawski's Formula

This formula is established on large-scale in situ tests on coal pillars. Such tests were first carry out in the United States by *Greenwald et al.* (1939) in the period 1933–1941. Broad tests were accompanied in South Africa during 1965–1973 by *Bieniawski*(1968, 1969), Wagner (1974), and *Bieniawski and van Heerden*(1975). *Wang et al.* (1977) accompanied in the United States the largest test of all connecting one full-sized coal pillar measuring 80 ft (24 m) in width. All these studies examined the various pillar-strength formulas.

To make the in situ test results usually applicable (i.e., not only to the neighborhood where the actual tests were carried out), the pillar-strength formula can be stated in a normalized form.

The general normalized form of the Bieniawski equation is:

$$\sigma_p = \sigma_1 \left(0.64 + 0.36 \frac{w}{h}\right)$$

Where σp is pillar strength, w is pillar width, h is pillar height, and σ1 is the strength of a cubical specimen of critical size or greater (e.g., about 3 ft or 1 m for coal).

Based on large scale testing of in-situ coal samples in South Africa and in USA. Recommended safety factor range 1.5 to 2.0

2.4.5 CMRI Formula

CMRI developed a formula for pillar strength taking into account the pillar w/h ratio, the uniaxial compressive strength of the pillar, the height of seam and depth of cover.

$$S = \ 0.27 \times \sigma_c \times h^{-0.36} \ + \ \frac{H}{160}\ \frac{w}{h} - 1$$

S = Pillar strength (MPa)

σ_c = Uniaxial compressive strength (UCS) (MPa)

h = Working height or seam height (in m)

H = Depth of cover (in m)

w = Pillar width (in m)

2.4.6 Salamon-Munro Formula

$$\sigma_p = 1.32 \frac{w^{0.46}}{h^{0.66}}$$

$$Strength = \frac{19.05}{(w^{0.133}h^{0.066})}\left\{0.237\left[\left(\frac{w}{5h}\right)^{2.5}-1\right]+1\right\} \quad \mathbf{w/h>5}$$

Taking into account the 125 case histories in South African coal fields. Where S_p is communicated in psi and MPa and column measurements are in ft and m in English and SI units individually. Prescribed wellbeing variable for utilizing this recipe is 1.6, the reach being 1.31 to 1.88.

DGMS GUIDELINES FOR PILLER DESIGN

According to DGMS coal mine regulations 1957 no 99, the pillar dimension is given based on the depth of the cover as shown in the following Table. This guideline ignores the in situ strength of the coal and thus probably over/under estimate the pillar dimension**.**

Table: 2.1 pillar dimension based on the depth of the cover

Depth of seam from surface	The distance between centers of adjacent pillars shall not be less than			
	Where the width of the galleries does not exceed 3.0 meters	Where the width of the galleries does not exceed 3.6 meters	Where the width of the galleries does not exceed 4.2 meters	Where the width of the galleries does not exceed 4.8 meters
(1)	(2)	(3)	(4)	(5)
	Meters	Meters	Meters	Meters
Not exceeding 60 meters	12.0	15.0	18.0	19.5
Exceeding 60 but not exceeding 90 meters	13.5	16.5	19.5	21.0
Exceeding 90 but not exceeding 150 meters	16.5	19.5	22.5	25.5
Exceeding 150 but not exceeding 240 meters	22.5	25.5	30.5	34.5
Exceeding 240 but not exceeding 360 meters	28.5	34.5	39.5	45.0
Exceeding 360 meters	39.0	42.0	45.0	48.0

CHAPTER 3

GEOMINING CONDITIONS OF CASE STUDIES

3.0 GEOMINING CONDITIONS OF CASE STUDIES

3.1 RK.6 INCLINE, SCCL

3.1.1 GEOMINING CONDITIONS

Earlier1A, 1 seams were not proposed to develop due to low grade quality of coal. After selective mining No.1A and No.1 seam are developed. No.2B seam and No. 3 seam are partially developed and stopped due to low thickness. In RK6A Section, 1A seam, depillaring is under progress with SDL machines thesis done by conventional method of mining. No.1 seam partial development; this is done by conventional method of mining. Presently part of seam is Non-workable. Table 1 and Fig 1 shows Strata section in Borehole number 534. Figures below illustrates location of workings in panels 1AS1, 1AS2, and 1AS3.

3.1 Seam Details

Table3.1: Details of the strata section.

Seam	***1A***	***1***	***2B***	***2A***	***2***	***3***	***4***	***5***
Thickness(m)	3.60-5.8	2.8-3.2	0.6-1.2	1.5-2.6	4.2-4.7	0.9-1.2	1.6-1.8	1.6-2.0
Parting(m)	18	40	11	25	35	12	11	
Gradient1in4								
Overall quality E								
Gassiness I degree								
ExtractableReservesason01-08-2012				6 .00MT.				

Panel No.	No. of pillars	Size of the panel
1AS1	36	400 M x 105 M
1AS2	23	225 x 145 m
1AS3	40	277 m x 175 m

In No 2Aseam 19 panels were depillared and 6DS to 6DN are standing on pillars. 2A seam Sector B development towards dip side is under progress, this is done by conventional method of mining No.2 seam was developed up to dip side mine boundary 15 panels were depillared by conventional method of mining. In RK6 Section, 4 & 5 Seams 6 panels were simultaneously depillared towards North side by conventional method of mining. Now in No. 4 seam south depillaring is under progress and this is done by conventional method of mining with SDLs. The expected remaining life of the mine is 7 years

Surface RL 874.71 m

Meter age		**Strata**
5.00		Surface soil
49.00		Brown sand stone
60.94		Grey sand stone
5.59		No.1A Seam (Proposed Panel)
13.85		Grey sand stone
3.32		**No.1 Seam**(Standing on pillars)
37.92		Grey sand stone
0.41		**No.2B Seam**(Virgin)
9.56		Grey sand stone
1.48		**No.2A Seam**(Standing on pillars)
26.13		Grey sand stone
4.85		**No.2 Seam**(Standing on pillars)
28.24		Grey sand stone

0.46		**No.3 Seam**(Virgin)
16.39		Grey sand stone
0.60		**No.4 Seam**(Virgin)
10.11		Grey sand stone
0.55		**No.5 Seam**(Virgin)
4.41		Grey sand stone

Fig 3.1: Strata section in Borehole number 534

3.1.2 Condition of the Workings

1AS3 panel of No.1A Seam having thicknesses is about 4.6 to 5.5 m dipping at 1 in 7 gradient having been developed up to 3.0m along the sand stone roof. The number of the pillars and the size of the panel is presented in Table 2.

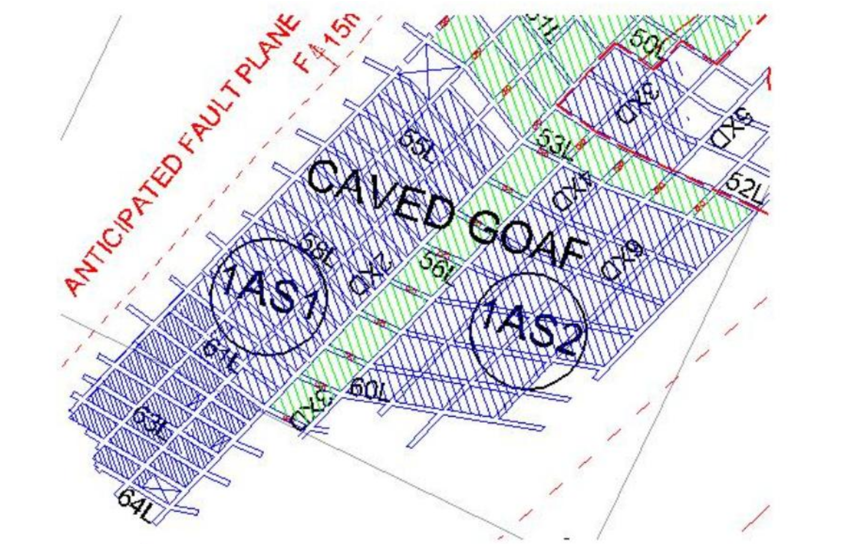

Fig 3.2: Location of panels 1AS1 and 1AS2 IN RK 6 incline

Table 3.2: Details of the pillars

Panel No.	Width of the galleries			Height of the Galleries (in m)			Size of the pillars (m)			Depth of cover (m)		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1AS1	5.3	3.5	4.4	3.6	2.4	3.00	37 x 35	35X 33	35X 35	194	143	168.50
1AS2	5.3	3.5	4.4	3.6	2.4	3.0	47 x 35	37 x 35	42 x 35	187	143	165
1AS3	5.1	3.5	4.3	5.4	2.5	3.00	34 x 44	32 X 25	35 X 32	138	108	123.5

3.2 GDK.8 INCLINE,SCCL

Godavarikhani no.8 incline, existing in the southern extension of- South Godavari mining lease. It falls in Ramagundam Taluq of Karimnagar District of Andhra Pradesh State. It lies between Latitude: 18-50 and Longitude: 79^0 -28’ & 79^0 -35’. The 5.60 Sq. Km. of the leasehold is a strip of 68.48 Sq.KM LEASED AREA OF South Godavari coal Field, belonging to SCCL. The mine is approximately 20 KM from Ramagundam Railway station, 10 km from central screening plant & Railway siding of GDK.No.1 incline. It is 60 KM from Karimnagar and about 220 KM from Hyderabad by road. South side GDK 10 & 10A Inclines.

Godavarikhani No.8 Incline, existing in the southern extension of – South Godavari Mining Lease. It falls in Ramagundam Taluq of Karimnagar District of Andhra Pradesh State. It lies between Latitude: 18 –50 and Longitude: 79^0 –28’ & 79^0-35’.The 5.60 Sq.K.m of the leasehold is a strip of 68.48 Sq.KM leased area of South Godavari Coal Field, belonging to Singareni Collieries Company Limited. The Mine is approximately 20 KM from Ramagundam Railway station, 10 km from Central screening plant & Railway siding of GDK.No.1incline. It is 60 KM from Karimnagar and about 220 KM from Hyderabad by Road. South side GDK 10 & 10 A Inclines. North side Identified for OCP 2 Mine extension Block, Dip side part of OCP 2 & part of OCM 1-Extension Phase-II. The Gondwana series slightly dipping in North-Easterly consists here in the property the Barker and Talchirformation. The production was started on 1974 with the life time about 38 years and extractable reserves of 36 MT. The average daily production was consistently more than 1400 t, with good production records. Till now 24 B G panels were successfully. The gradient of mine is 1 in 8. The grade of coal is ‘D’ grade. Total number of seams encountered the area are seven namely – 1A,1,2,3B,3A,3 and 4seams, of which No.1,2,3 and 4 seams are considered to be workable. The strata within the boundaries are gently anticlerical in structure.

Table 3.3: Thickness of seams as in Boreholes

Seam No.	Borehole No	Minimum Thickness	Borehole No	Maximum Thickness
1seam	105	5.3m	109	6.7m
2seam	93	3.0m	103	8.5m
3seam	139	7.3m	241 &197	10.67m
4seam	241	1.82m	265 & 270	3.97m

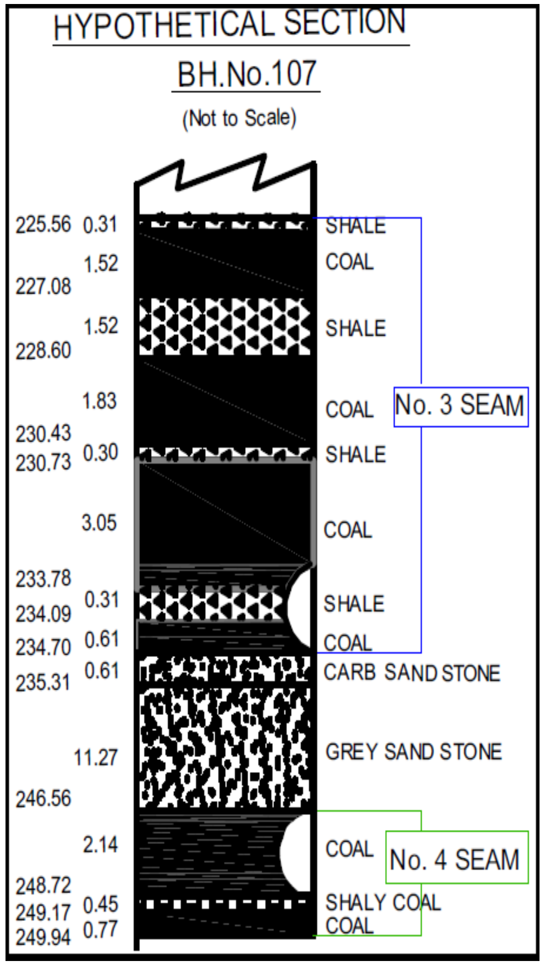

Fig. 3.3 Borehole section at GDK-8 Incline

3.2.1 Mining Practice

Main Entries

There are two inclines driven from surface to 3 & 4 seams namely Main Incline and Man way. Two Shafts were driven from surface to 3 & 4 seams; one of the shafts is serving as Intake and other one as main return. Man riding system is installed and commissioned in Main Incline. Man riding system is operating at present from surface to 48 Level. Coal conveying is through belts & belt conveyors are installed in man way.

ii) Seams Being Worked

No. 3 seam**:** Thickness of No.3 seam varies from 9.0 m to 10.5 m. Quality of the coal is "D" Grade. At certain places it is developed in two sections i.e. top and bottom & at certain places only bottom section is developed. In 3 seams depillaring was carried out by Blasting Gallery method.

No. 4 seam: Thickness of No.4 seam varies from 3.0 m to 4.0m. Total workable reserves are about 11.8 MT. Grade of coal is 'B'. The seam was fully developed by board and pillar method. Extraction of the pillars was being done by sand stowing. Fig.2a, and Fig 2b shows layout of BG panels and working plan of panel 10A/10B, respectively in GDK -8 incline. Details of panels worked at GDK 8 incline are presented in Table 2. Fig 3 shows a key plan of stowing panel SS 10 in seam #4 with a parting of about 11 m beneath the BG workings of seam #3.

iii) Worked out Districts:

4 SEAM:	a) SS-10 panel	-	Depillaring by Sand Stowing.
	b) SS-11N panel	-	Depillaring by Sand Stowing.
3 SEAM:	a**)** BG –II/10B panel	-	Depillaring by Blasting Gallery Method.
	b) BG-II/ 10APanel	-	Depillaring by Blasting Gallery Method.

Table 3.4: Details of panels worked at GDK 8 incline

DETAILS	BG II/10 A	BG II/10B	SS 10
Area of panel	12,800 M^2	14,600 M^2	45,000 M^2
Depth from surface	Min:220 m; Max: 234m.	Min:223 m; Max: 239m.	Min:235 m; Max: 255m.
Average pillar size	Min-34.5m *34.5m. Max-52m*34.5m.	Min-35m *45m. Max-52m*35m.	34 M-length 35 M- width

Extractable reserves	1,28,000 T	1,47,000 T	85,000 T
Expected output/month	25,000T	25,000T	10,000 T
Number of pillars	7 Pillars	8 Pillars	35 Pillars
Life of panel	5 Months	6 Months	9 Months
Coal extracted	1,29,218 T	1,07,427 T	76,425 T

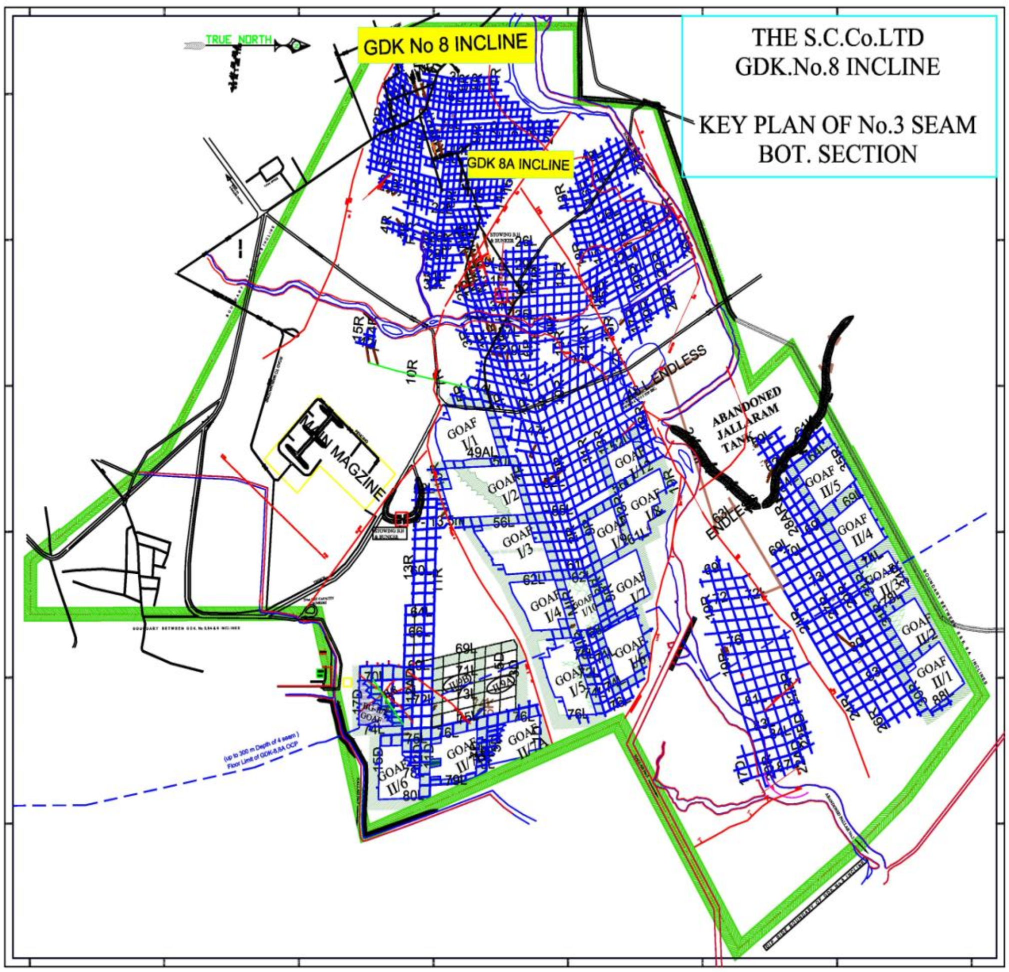

Fig.3.4 Mine Plan showing developed pillars and the BG panels in GDK -8 incline

CHAPTER 4

APPLICATION OF VARIOUS APPROACHES

4.1Data of RK.6 INCLINE

H= depth of cover = 210m

B= width of mined out area= 8m

(γ)Unit rock pressure= 0.025 MPa

w= width of pillar = 30m

α= dip of the seam=14^0

R= extraction ratio =0.235

W_1= width of pillar = 30m

W_2= width of pillar =30m

Gallery width = 4.5m

L= extraction width =8m

σ_c=compressive strength= 360 kg/cm^2=$360\times9.81\times10^4$ Pa

h= extraction height=5.5m

4.2LOADS ON THE PILLARS

4.2.1 Tributary Area Approach

Normal stress, 6_n=0.025×210($\cos^2 14^0$+0.5 $\sin^2 14^0$)

=5.25(0.0187+0.5×0.981)
=5.25×0.5092
=2.67MPa

Average stress on the pillar,

$$P = 6_P = \frac{2.67}{1-0.235} = 3..49\text{MPa}$$

Pillar stress,

$$6_p = \frac{0.025\times210}{1-0.235} = 6\ .863\text{MPa}$$

Safety factor=$\frac{360\times9.81\times10000}{6.86\times1000000}$=5.15

4.2.2Wilson's Approach

$$P= 0.025(30+4.5)\frac{210(30+8\ -\ 36\div1.2\ )}{30\times30}$$

=7.62MPa

4.3PILLAR STRENGTH EQUATION

4.3.1 Overt-Duvall Formula

S_P=6.2(0.778+0.222× $\frac{30}{5.5}$)

=12.33MPa

4.3.2Holland- Gaddy Formula

S_P= 0.5× $\frac{\sqrt{30}}{5.5}$=0.498 MPa

4.3.3 Holland Formula

$S_P=6.2\sqrt{\frac{30}{5.5}}=14.48$ MPa

4.3.4Salamon-Munro Formula(1967)

$S_P=7.2\times(30^{0.46}\div5.5^{0.66})=11.17$MPa

4.3.5Bieniawski's Formula

$S_P=6.2(0.64+0.36\times(30\div5.5))=16.14$MPa

4.3.6 CMRI Formula

$S=0.27\times360\times9.81\times10^{4}\times5.5^{-0,36}+(210\div160)\ (30/5.5-1)$

$=12.08$MPa

4.4 Data of GDK.8 INCLINE

H= depth of cover = 225m

B= width of mined out area= 8m

(γ)Unit rock pressure= 0.025 MPa

w= width of pillar = 34.5m

α= dip of the seam=20^0

R= extraction ratio =0.163

W_1= width of pillar = 50m

W_2= width of pillar =34.5m

Gallery width = 4.2m

L= extraction width =8m

6_c=compressive strength= 400 kg/cm^2=400×9.81×10^4 Pa

h= extraction height=6m

4.5 LOAD ON THE PILLARS

4.5.1 Tributary Area Approach

Normal stress, $6_n=0.025\times225(\cos^2 20^0+0.5\sin^2 20^0)$

$=0.025\times225(0.88+0.5\times0.117)$

=5.279MPa

Average stress,

$P=6_P=\frac{5.279}{1-0.163}=6.307$MPa

Pillar stress,

$$6_p=\frac{0.025\times225}{1-0.163}=6.720\text{MPa}$$

4.5.2 Wilson's Approach

$$P=0.025(34.5+4.2)\frac{225(50+8-64\div1.2)}{50\times34.5}$$

$=7.29$MPa

4.6 PILLAR STRENGTH EQUATION

4.6.1 Overt-Duvall Formula

$S_P=6.2(0.778+0.222\times \frac{34.5}{6})$

$=12.74\text{MPa}$

4.6.2 Holland- Gaddy Formula

$S_P= 0.5\times \frac{\sqrt{34.5}}{6}=0.49$ MPa

4.6.3 Holland Formula

$S_P=6.2\sqrt{\frac{34.50}{6}}=14.87$ MPa

4.6.4 Salamon-Munro Formula(1967)

$S_P=7.2\times(34.5^{0.46}\div 6^{0.66})=11.25\text{MPa}$

4.6.5 Bieniawski's Formula

$S_P=6.2(0.64+0.36\times(34.5\div 6))=16.802\text{MPa}$

4.6.6 CMRI Formula

$S=0.27\times 400\times 9.81\times 10^4\times 6^{-0,36}+(225\div 160)\ (34.5/6-1)$

$=13.14\text{MPa}$

CHAPTER 5

RESULTS AND ANALYSIS

5.0 RESULTS

Stress on pillars according to the tributary area approach in RK6 and GDK 8 incline mines are estimated to be about 6.86 MPa, 6.307 MPa, respectively (Table 5.1). Strength of pillars in the corresponding mines are in the range of 11.17MPa - 16.14MPa for RK6 and 11.25MPa - 16.802MPa, respectively (Table 5.2)

Table 5.1: Stress on the pillars

	RK.6	GDK.8
TRIBUTARY AREA APPROACH	6.86 MPa	6.307 MPa
WILSON'S APPROACH	7.62 MPa	7.29 MPa

Table 5.2: Strength of the pillars

	RK6	GDK8
OVERT DUVALL FORMULA	12.33MPa	12.74MPa
HOLLAND FORMULA	14.48MPa	14.87MPa
SALAMON MUNRO FORMULA	11.17MPa	11.25MPa
BIENIAWSKI'S FORMULA	16.14MPa	16.802MPa
CMRI FORMULA	12.08MPa	13.14MPa

5.1 ANALYSIS

Stability of the pillars is estimated through the empirical equations; five approaches for estimation of pillar strength and two approaches for estimation of pillar stress. Calculated safety factors are presented in Table 5.3. Tributary area approach for pillar stress and Bieniawski approach for pillar strength gave maximum safety factor of 2.35, and 2.66 for the conditions of RK-6, and GDK 8 Mine, respectively. Similarly with the stress estimation through Wilson's approach assuming goaf on one side of pillars, safety factor was found to be comparatively less. Safety factors are 2.11 and 2.3 for RK-6, and GDK 8 with variation of about 10% compared to the Tributary Area Approach. On the whole, pillars are stable with more than 1.5 safety factor for both of the mines conforming to the field observations.

Table 5.3 Safety Factor of Pillars As Per Different Approaches

STRENGTH EQUATIONS	SAFETY FACTOR			
	Tributary Area Approach		Wilson's Approach	
	RK6	GDK8	RK6	GDK8
OVERT DUVALL FORMULA	1.79	2.019	1.61	1.74
HOLLAND FORMULA	2.11	2.35	1.90	2.03
SALAMON MUNRO FORMULA	1.62	1.78	1.46	1.54
BIENIAWSKI'S FORMULA	2.35	2.66	2.11	2.30
CMRI FORMULA	1.76	2.08	1.58	1.80

CHAPTER 6

CONCLUSION

6.0 CONCLUSIONS

Based on analysis of field data for RK6 and GDK8 incline, and empirical model studied on stability of pillars, the following conclusions are drawn:

1. Tributary area approach on stress over the pillars indicated maximum stress of 6.86MPa, 6.3MPa in RK6 and GDK8 respectively.
2. Wilson's approach on stress over pillar shows maximum stress of 7.62MPa and 7.29MPa respectively for mine RK6 and GDK8 incline.
3. Strength of the pillars through six approaches indicated minimum strength of 11.17MPa and 11.25MPa in RK6 and GDK8 respectively.
4. Safety factors are 2.11 and 2.3 for RK-6, and GDK 8 with variation of about 10% compared to the Tributary Area Approach. On the whole, pillars are stable with more than 1.5 safety factor for both of the mines conforming to the field observations.

REFERENCES:-

1. SALAMON, M.D.G., and ORAVECZ, K.I. Rock mechanics in coal mining. Johannesburg, Chamber of Mines of South Africa, P .R.D. Series No. 198, 1976.

2. Lombard, H.E., Fourie, G.A., Cox, A.J., DU Plesis, A.G. and Wilson, R.B. Review of access design and mining method of the 44E room and pillar mine design, Interim Report, SRK-Turgis. 2001. pp. 1–10.

3. Bieniawski Z.T., ―SME Mining Engineering Handbook‖ , Society for Mining, Metallurgy, and Exploration, Inc. Littleton, Colorado· 1992 2nd Edition, Chapter 10.5, pp 923-970

4. Bieniawski, Z. T., 1984, Rock Mechanics Design in Mining and Tunneling, A.A.Balkema.

5. Sheorey P. R. Pillar strength considering in situ stresses. Workshop on Coal Pillar Mechanics and Design, pp. 122-127. Santa Fe, USBM IC 9315 (1992)

6. https://circle.ubc.ca/bitstream/id/14429/ubc_1994-0501.pdf

7. https://www.google.co.in/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CCIQFjAA&url=http%3A%2F%2Fstacks.cdc.gov%2Fview%2Fcdc%2F8291%2Fcdc_8291_DS1.pdf&ei=TZRMVfP5JsmLuwSavoHgCw&usg=AFQjCNGfpBTFzjqAarzofPkZ7CtE6REcg&bvm=bv.92765956,d.c2E

8. http://ac.els-.com/S0148906298001685/1s2.0S014890629800168main.pdf?tid=fec1d14c- f56d-11e4 908400000aacb35f&acdnat=1431081530_eed50dec3c8c779a7db59890ee08c63a

9. http://www.cdc.gov/niosh/mining/userfiles/works/pdfs/sota.pdf